Pestic. Sci. 1997, **51**, 367–370

SAMOA™†: One Company's Approach to Herbicide-Resistant Weed Management*

Dale L. Shaner,‡ David A. Feist & E. James Retzinger

American Cyanamid Co., PO Box 400, Princeton, NJ 08543 USA

(Received 1 May 1997; revised version received 11 July 1997; accepted 25 July 1997)

Abstract: SAMOA (Second Active Mode of Action) is a program that was developed by American Cyanamid as a way to prevent/delay selection of resistance to the imidazolinones and to manage resistant weed populations if they are selected. The program consisted of three major components, all of which had to be implemented for the program to be successful. These components comprised educating sales persons, distributors and farmers on resistance management, developing efficacious and cost-effective tank mixtures or sequential programs and providing incentives for using this program.

Pestic Sci., **51**, 367–370, 1997
No. of Figures: 0. No. of Tables: 1. No. of Refs: 15

Key words: resistant weed management, imidazolinones

1 INTRODUCTION

The selection and management of herbicide-resistant weed populations has received increasing attention throughout the 1990s. This attention is due to the selection of weed populations resistant to several of the newer families of herbicides, particularly the cyclohexanediones and aryloxyphenoxypropionates (Acetyl CoA Carboxylase (ACCase) inhibitors) and the sulfonylureas, triazolopyrimidine sulfonamides and imidazolinones (Acetolactate Synthase (ALS) inhibitors). These herbicides play a primary role in the weed-management programs for most of the major crops and account for almost 20% of the global herbicide market.[1]

Thus, it is important that their utility be maintained for as long as possible. The selection of resistant weed populations could limit their utility, and companies are taking steps to delay the selection of resistant weed populations and to manage those populations that have already developed resistance.

Resistance management consists of both technical and managerial elements.[2] The technical elements are a property of the herbicide itself and cannot be altered, but the managerial elements, which relate to how a company recommends the use of a herbicide, are more controllable by the manufacturer. These managerial elements include

use recommendations of the herbicide
integration of the herbicide with other weed-control methods
enforcement of the recommendations
acceptance of the recommendations by other companies, academia and users
coordination of recommendations with manufacturers of herbicides with the same mode of action and used in the same crop
implementation of the recommendations by the user.

The imidazolinone herbicides are mostly used in leguminous crops and in imidazolinone-resistant maize and canola. The imidazolinones are widely used because of

* Based on a presentation at the Conference 'Resistance '97—Integrated Approach to Combating Resistance' organised by the Institute of Arable Crops Research in collaboration with the SCI Pesticides Group and the British Crop Protection Council and held at Harpenden, Herts, UK on 14–16 April 1997.
† Trademark American Cyanamid Company.
‡ To whom correspondence should be addressed.

 Pestic. Sci. 0031-613X/97/$17.50. Printed in Great Britain

TABLE 1
Herbicide Resistance Management Planning Worksheet[a]

Year	(*Three years ago*) *1994*	(*Two years ago*) *1995*	(*Last year*) *1996*	*Current year 1997*	
Crop	Corn	Soybean	IMI-Corn™	Soybean	
Herbicide program	Cyanazine Metolachlor PRE	Pendimethalin Imazethapyr PRE	Dimethanamid Imazethapyr Dicamba PRE & POST	Pendimethlin Imazethapyr Thifensulfuron Lactofen PPI & POST	
Key weeds[b]	*Site of action classification*[c]				*Number of sites of action classification on key weeds in the time period*
SEFTA	15	3, 2	5, 2	3, 2	4
ECHCG	15	3, 2	5, 2	3, 2	4
AMARE	15	3, 2	2, 4	3, 2	4
CHEAL	5	3	4	14	4
AMBEL	5	2	2, 4	2	4

[a] Reference 5.
[b] From Reference 15. SETFA-*Setaria viridis;* ECHCG-*Echinochloa crus-galli*; AMARE-*Amaranthus retroflexus;* CHEAL-*Chenopodium album;* AMBEL-*Ambrosia artemisiifolia.*
[c] Classification numbers from Retzinger and Mallory-Smith.[13]
™ Trademark American Cyanamid Company for imidazolinone-resistant corn varieties.

their efficacy and highly desirable environmental and toxicological characteristics.

However, resistant weed populations can be selected through the continuous use of these herbicides on the same field for several years. The first case of resistance to the ALS inhibitors was reported in Idaho in 1987, when a population of *Lactuca serriola* L. was no longer controlled by chlorsulfuron.[3] Subsequently there have been several reports of weed populations that are resistant to ALS inhibitors throughout the world.[1,4]

In most cases where resistance has been selected by an ALS inhibitor, it has occurred where this mechanism of action was used alone over an extended period of time on the same field. One of the ways to prevent or delay the selection of resistance is to use a mixture of herbicides with different modes of action, either as a tank mix or in sequential applications.

As listed above, the managerial elements of resistance management include not only recommending how a herbicide is used but also acceptance of those recommendations. We developed a program within Cyanamid called SAMOA to address herbicide resistance management. This paper describes the various components of the SAMOA program as an example of one company's approach to resistance management.

The SAMOA program has multiple components. These include

—education of Cyanamid sales staff, distributors and users on herbicide resistance
—development of recommendations for effective herbicide pre-mixes or tank mixtures or sequential programs for resistance management
—incentives for farmers to implement these programs.

2 EDUCATION

One of the first steps in implementing SAMOA was to educate the sales staff on what resistance is, how it happens and what can be done about it. As with any new situation, it was important to stress that herbicide resistance is not new and can be managed with the proper weed management program. Once the sales staff were knowledgeable, the distributors of the herbicides needed to be informed of the SAMOA program's goals and how these were going to be implemented. Finally, we provided information to the farmer on herbicide resistance and how SAMOA could be used to manage it.

The technical service staff developed many different educational pieces for training both the sales staff and distributors, who could then pass this information on to the grower. This information included slide sets, question/answer sheets and a pamphlet entitled 'Herbicide Resistance in Weeds: An overview'. These educational materials were widely distributed. The pamphlet defined the terms used in describing herbicide resistance

and explained how resistance to a herbicide occurs. It also provided answers to many of the questions that arise when herbicide resistance is encountered. Finally, it explained how resistance can be prevented/delayed and managed by using an integrated approach to weed management including:

1. read and follow the herbicide label
2. use tank mixes or sequential applications of herbicides with different mode of action
3. practice crop rotation
4. use a minimum number of herbicide applications per season
5. follow recommendations of university and extension advisers for optimum rates of herbicides needed for economic weed control
6. combine tillage practices with herbicide treatments when possible.

One of the biggest obstacles in training sales staff, distributors and farmers was their difficulty in identifying herbicides by their mechanisms of action and utilizing this information in a practical way to develop an efficacious weed-management program. To overcome this obstacle, we developed a table which could be used with the farmer to analyze his weed-management program and to determine whether or not it would fit a SAMOA strategy (Table 1).[5] This table was coupled with other tables which classified herbicides according to their site of action.

In this table the farmer lists his crop rotation over multiple years, the weeds he is trying to manage and the herbicide he uses. He then determines how many herbicides with different mechanisms of action were used to control each weed species over a multi-year period. If a certain weed is only being controlled by one mechanism of action, there is an increased risk of selecting for resistance to that mechanism of action. The sales staff found this format very helpful in explaining resistance management and in analyzing a grower's weed management program quickly and easily. It also helped in making recommendations for decreasing the risk of selecting for resistance, not only to the imidazolinones, but to other herbicides.

To disseminate this information to growers, the SAMOA program was explained to a number of writers for popular agricultural publications. These writers, in turn, included this information in a number of articles on herbicide resistance in their magazines.[6–9]

3 RECOMMENDATIONS

Another vital component of SAMOA is the recommendation for formulated herbicide mixtures, tank mixtures or sequential programs of herbicides that are the most efficacious and cost effective. Wrubel and Gressel[10] pointed out that in order for a herbicide mixture to be useful for delaying the rapid selection of resistance, ideally the herbicides in the mixture should have the following characteristics:

control the same spectrum of weeds
have similar persistence characteristics in order to control the same cohorts of weeds
have different target sites
exert negative cross-resistance
be degraded by different pathways.

From a practical point of view the first three of these characteristics are those that can be measured, at least partly, in the field through standard field trials and can be used to determine the best mixtures for resistance management. However, negative cross-resistance is less easily measured and appears to be relatively rare, and the pathways of degradation depend on the chemistry, may be complex and may differ among weed species. In addition, tank mixtures have to be cost-effective. If the mixture is too expensive, then there will be little incentive for the farmer to adopt the more expensive mixtures until he is forced to.

Keeping all of these facts in mind, many field studies were conducted to determine the best combinations of herbicides to use, either as mixtures or in sequential programs with the imidazolinones to provide efficacious weed control while being cost-effective. The criteria used to determine if a tank-mix partner was efficacious were:

1. It had to provide at least 85% weed control under field conditions in multiple locations.
2. It had to control the same weed as the imidazolinone for the whole season.
3. It had to give minimal crop injury.

In a multi-site study conducted in 1994, various potential tank-mix partners for imazethapyr for use in imidazolinone-resistant corn were evaluated.[11] Using the above criteria, it was determined that bentazone was a good SAMOA partner if the target weeds were *Abutilon theophrasti* Medicus., *Polygonum pennsylvanicum* L. or *Helianthus annuus* L. On the other hand, if the target weeds included *Chenopodium album* L., *Amaranthus* sp., *Xanthium strumarium* L. or *Sinapsis arvensis* L., bromoxynil was a better SAMOA partner. Dicamba was a good partner if the target weeds included *C. album*, *Amaranthus* sp., *Ambrosia artemisiifolia* L., *X. strumarium* or *Datura stramonium* L.

Similar studies were conducted on different herbicide combinations for weed management in soybean. This work clearly showed that the specific SAMOA recommendation depended on the weed spectrum, the crop rotation pattern and the herbicides available. The flexibility of this program demonstrated how these mixtures could fit into different agronomic situations.

4 INCENTIVES

In addition to providing information on the means for managing herbicide resistance and recommending specific herbicide mixtures or sequential programs for resistance management, Cyanamid also provided economic incentives for adopting the SAMOA program. This included offering formulated mixtures of imidazolinones with other herbicides which were less expensive than buying the herbicides alone and mixing them, and offering rebates to growers if they used a SAMOA program which included applying herbicides with two different modes of action.

Although the effectiveness of the SAMOA program is difficult to measure, farmers who had a weed-management program that included mixtures of herbicides with different mechanisms of action coupled with crop rotation, tillage and various cultural practices were less likely to select herbicide-resistant weed populations. Farmers who had selected resistant populations and then implemented the SAMOA program were able to manage their resistant population effectively.[12]

5 OBSTACLES

A private survey (unpublished) of a selected group of farmers was conducted by Cyanamid to determine their perceptions of herbicide resistance and how to manage it. We found that farmers did not have a clear understanding of how resistance develops. In addition, many of the farmers surveyed did not know the different mechanisms of action of herbicides or which herbicides shared a mechanism of action. They were more apt to group herbicides by their use pattern (e.g. soil-applied versus foliar-applied) than by their mode of action. (Part of the reason for this was that there is limited information on the classification of herbicides by their mechanisms of action. This will soon be remedied).[13,14] Farmers' major concern about resistance was the cost of implementation of resistance management.

These responses clearly point to the primary obstacles for implementation of resistance-management strategies. The system has to be simple enough for the farmer to grasp quickly and it has to be cost-effective in order for the farmer to implement it. If the cost and effort of prevention is the same as that of the cure, farmers are reluctant to change their program until after resistance has occurred. Even after extensive efforts to explain the advantages of the SAMOA program, not only for resistance management, but also for overall weed management, and providing economic incentives for adopting the program, many farmers implemented the program only after resistance had developed. In spite of this, we found that using a program approach to resistance management was highly effective for training and for providing a powerful tool to our sales staff for helping a farmer manage resistance.

REFERENCES

1. Powles, S. B., Preston, C., Bryan, I. B. & Jutsum, A. R., Herbicide resistance: impact and management. *Adv. Agr.*, **58** (1997) 57–93.
2. Shaner, D. L., Sinha, A. & Braddock, R., Designing strategies to delay development of resistance to herbicides. *Proc. First Int. Weed Control Congress, Melbourne.* **I** (1992) 236–9.
3. Saari, L. L., Cotterman, J. C. & Thill, D. C., Resistance to acetolactate synthase-inhibiting herbicides. In *Herbicide Resistance in Plants: Biology and Biochemistry*, ed. S. B. Powles and J. A. M. Holtum. CRC Press Inc., Boca Raton, USA, 1994, pp. 83–140.
4. Horak, M. J. & Peterson, D. E., Biotypes of palmer amaranth (*Amaranthus palmeri*) and common water hemp (*Amaranthus rudis*) are resistant to imazethapyr and thifensulfuron. *Weed Tech.*, **9** (1995) 193–5.
5. Fore, Z., *Herbicide Resistance Management Workbook: Manage Weeds Before They Manage You.* Cenex/Land O'Lakes Agronomy Company, Hutchinson, MN, USA, 1995.
6. Horstmeier, G. D., Resisting resistance. *Farm Jour.*, Jan. (1994) pp. S-1–S-4.
7. Ferguson, J., Re-thinking rotations. *Ag. Consultant*, April (1994) p. 14.
8. Brunoehler, R., Herbicide buys help beat resistance. *FIN*, Mid-Feb. (1995) pp. 38–46.
9. Holmberg, M., Multiple modes. *Successful Farming*, Jan. (1995) pp. 48–9.
10. Wrubel, R. P. & Gressel, J., Are herbicide mixtures useful for delaying the rapid evolution of resistance? A case study. *Weed Tech.*, **8** (1994) 635–48.
11. Retzinger, E. J., Fellows, G. M., Foland, E. L., Schuh, J. F., Busse, S. R. & Smith, W. A., Weed resistance management tank mixtures for imi-corn. *Proc. North Central Weed Sci. Soc.*, **50** (1994) 140.
12. Tipton, H., Field test. *Cotton Farming*, April (1995) p. 7.
13. Retzinger, E. J. & Mallory-Smith, C., Classification of herbicides by site of action for weed resistance management strategies. *Weed Tech.* **11** (1997) 384–93.
14. Schmidt, R. R., HRAC classification of herbicides according to mode of action. *Proc. Brighton Crop Prot. Conf.* (1997) in press.
15. Anon. *Composite List of Weeds*, Revised 1989. Obtainable from WSSA, 1508 West University Avenue, Champaign, IL 61821, USA.